UHF RFID Transmission with Soft-Input BCH Decoding

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***Abstract*—Radio Frequency Identification (RFID) is a wireless communication method mostly used in rough indoor environments. In such environments Forward Error Correction (FEC) is a popular method to improve the transmission quality. However, the common RFID protocol (EPCglobal) only provides error detection based on Cyclic Redundancy Check (CRC) codes. The replacement of this code with an arithmetically similar FEC code improves the transmission and requires only minor changes to the protocol structure. A BCH code fulfills this requirement. Nevertheless, this code has the disadvantage that it uses only hard-coded bits for the decoding process. This work presents a BCH decoding using the Chase algorithm which also takes the soft information of the received sequence into account. It is shown that a coding gain of $1\ dB$ is achievable in an RFID transmission application, compared to a transmission with a common BCH code. Also an estimation of the computational complexity when using the Chase algorithm is given as this complexity generally increases with this modification.**

I. Introduction

The EPCglobal Class-1 Gen-2 protocol [1] defines the UHF RFID wireless communication where one reader interacts with an unknown number of transponders (tags) over several meters. This protocol does not provide any form of Forward Error Correction (FEC). This is reasonable for systems with passive tags [2], as the bottleneck of such a system is the received power at a transponder [3]. In this case additional FEC would not increase the system performance significantly. Nevertheless, the communication with semi-passive tags [2] depends on the sensitivity of the reader. In this case an FEC would improve the transmission quality.

The EPCglobal uses a CRC code [4] which allows a very reliable error detection but no error correction. Replacing this code with an error correcting BCH code [5] increases the performance of the transmission system. Previous work [6] shows a coding gain of up to $8\ dB$ using BCH codes during RFID communication. Due to the similarities between CRC and BCH codes, the replacement is possible with minor changes of the EPCglobal protocol. The authors are aware of the lack of detection ability when the CRC is not part of the communication. This problem is considered in [7] and is not part of this work.

A disadvantage of a common BCH code is that it uses only hard-coded bit values for the decoding process. This work presents the performance and complexity of a BCH decoder which takes the soft information of a received sequence into account. Therefore, the Chase algorithm is used which is first presented in [8]. Additionally, some modifications are made to achieve a good trade-off between performance and complexity. It will be shown that the communication with Chase decoding provides an additional coding gain of $1\ dB$ compared to a hard-coded BCH code without adding significant complexity.

The paper is organized as follows: Section II provides an overview of the EPCglobal RFID communication, the spreading sequences including their way of decoding and the transmission channel. Section III provides basic information on BCH codes. In Section IV the Chase algorithm is presented including the modifications made in this work. The performance of this algorithm is shown afterwards. Finally, a conclusion is drawn in Section VI.

II. RFID Communication

A transmission link between reader and transponder is shown in Fig. 1 where the reader/transponder blocks are shown in white/black, respectively. The BCH encoding replaces the CRC code and is not part of the current protocol. The differential decoding of the FM0/Miller spreading and the Chase decoding are not mentioned in the EPCglobal, either. Due to the higher sensitivity towards noise, this work focuses on the transmission from tag to reader (highlighted part of Fig. 1). For this transmission the data is encoded with a BCH code and a spreading sequence and send to the reader via backscattering [9] which is equivalent to an On-Off-Keying (OOK) modulation.

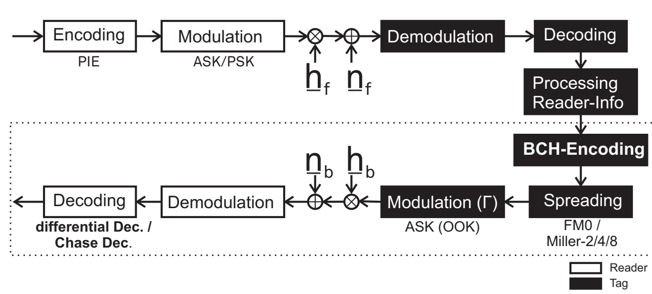

Fig. 1. UHF RFID transmission link

During the transmission a tag sends two packets to the reader. A Random 16 Bit Number (RN16) and a static Electronic Product Code (EPC) where both packets include a 22 bit preamble. Due to the protocol only the EPC is CRC-coded. This is taken into account when using BCH codes instead. Afterwards all bits are spread with FM0/Miller-sub-carrier sequences which spread each bit into $2, 4, 8$ or 16 chips, respectively. In the following only FM0 spreading is considered. For this spreading, an amplitude switch occurs in the middle of a zero bit and on the boundary of two bits.

The transmission channel is a Rayleigh Fading channel defined by Eq. (1) as it serves as a reference for fading channels which are common in an RFID scenario [10]

$$\underline{r}_i = \underline{h}_i \cdot s_i + \underline{n}_{AWGN}. \tag{1}$$

Here, s_i is the transmitted signal, $\underline{h}_i$ is a complex Gaussian channel factor representing the fading component and $\underline{n}_{AWGN}$ is complex Additive White Gaussian Noise (AWGN).

Note that the received signal is limited regarding its amplitude at the receiver in the following way:

$$0 \leq \mathrm{Re}(\underline{r}_i) \leq 1 \tag{2}$$

Previous work [6] shows a high performance increase using this modification.

A. Correlation of Spreading Sequences

The soft information at the receiver is generated via correlation of the noisy chip sequence $\underline{\mathbf{r}}$ (which includes L chips) and all possible bit symbols (two for every bit) $\mathbf{s_a} \in \{\mathbf{s_1}; \ldots; \mathbf{s_4}\}$ where every chip has the two possible values $s_{a,l} \in \{-1, 1\}$. The correlation is described by the following formula:

$$c_a = \frac{1}{L} \sum_{l=1}^{L} (2 \cdot \mathrm{Re}(\underline{r}_l) - 1) \cdot s_{a,l} \text{ with } \mathrm{Re}(\underline{r}_l) \in [0, 1]. \tag{3}$$

Afterwards the normed correlation value for one bit Δc_a is calculated as the difference of the maximal and minimal magnitude correlation.

$$\Delta c_a = c_{a,max} - c_{a,min} \tag{4}$$

Then the differential structure of the spreading sequences is taken into account. The soft information c is calculated as follows:

$$c = (1 - p_{pre} \cdot \Delta c_{a,pre})(1 - p_{next} \cdot \Delta c_{a,next}) \cdot \Delta c_a, \tag{5}$$

where $\Delta c_{a,pre}$ and $\Delta c_{a,next}$ are the normed correlation values of the previous and the next bit, respectively, and $p \in \{0, 1\}$ is a boolean variable indicating a conflict between the current and the previous/next bit. Finally, the correlation value c is normed analogous to formula (4).

$$\Delta c = c_{max} - c_{min} \tag{6}$$

This correlation provides a performance gain of $\approx 4\ dB$ due to the differential structure of the FM0 sequence. Note that even if a hard-input decoder is used, the differential decoding provides a certain coding gain due to the penalization in Eq. (5). To the authors' knowledge this detection scheme is not described in the context of UHF RFID communication, yet.

It should also be mentioned that as a result of this differential decoding soft information is provided as an input to the FEC decoding process. In this case a code which can use this soft information is worthwhile.

III. BCH Codes

BCH codes [5] are cyclic block codes which are parameterized by the values n and k, where n is the codeword length and k is the number of information bits, respectively. In this work the parameters are chosen as follows:

$$n = 255; \ k = 239.$$

These values imply $n - k = 16$ parity bits which are able to correct up to $t = 2$ errors in a codeword. This parity length is chosen because the EPCglobal provides a 16-bit CRC code for the EPC. For a more detailed view on the code generation and the en- and decoding of BCH codes it is referred to [11].

IV. Chase Decoding

The basic idea of a Chase decoder [8] is to generate binary error test patterns $\mathbf{T}$ and to apply they to the received hard-coded codeword $\mathbf{r}_h$ which results in the codeword $\mathbf{r}'_h = \mathbf{r}_h \oplus \mathbf{T}$. Here, $\oplus$ represents a logic XOR operation. This codeword $\mathbf{r}'_h$ is decoded by a hard decision BCH decoder which results in an error vector $\mathbf{e}_T = \mathbf{r}'_h \oplus \mathbf{d}$ for this particular error test pattern $\mathbf{T}$, where the BCH-decoded codeword $\mathbf{d}$ is XOR-connected to $\mathbf{r}'_h$. Afterwards an error weight is calculated with Eq. (7) based on the error vector and the correlation values of the spreading sequence (see Eq. (6) in Sec. II-A)

$$W_c(\mathbf{e}_T) = \sum_{k=1}^{n} \Delta c_k \cdot e_{T,k}. \tag{7}$$

Finally, the error pattern $\mathbf{e}_T$, which leads to the lowest error weight $W_{c,min}(\mathbf{e}_T)$, is modulo-2-added to $\mathbf{r}_h$ and decoded by a BCH decoder. With this procedure the bits which flip during the BCH decoding process are connected to their reliability values. As the most unreliable values have a higher possibility to flip during the transmission, this information is taken into account by the Chase algorithm.

A. Modifications

As a BCH code is a non-perfect code [11] there are certain received sequences which do not fit to a valid codeword even when an error test pattern is added to this sequence. While such a sequence is decoded in [8], the packet will be dropped in this work. This approach is called Bounded Distance Decoding [12] and has certain advantages regarding error detection, but does not influence the correction ability in a major way.

Furthermore, the basic Chase algorithm takes every error test pattern into account. This leads to an excessive amount of complexity especially when $t > 1$ errors are assumed. Chase [8] presented some alternatives to reduce the complexity of the previous algorithm. In the following, this work slightly modifies these alternatives. First, a threshold κ is introduced, which describes an upper bound for an error weight. Only error test patterns with a weight $W_c(T) < W_c(T_\kappa)$ are considered. With this assumption codewords which differ too much from the received sequence are dropped immediately. Second, the reliability values of one received sequence are sorted where the most unreliable bits are listed first. In the following all values are split into three blocks:

$$\mathbf{c}_{sort} = \left[c_{i,1} \dots c_{i,u} | c_{i,u+1} \dots c_{i,u+m} | c_{i,u+m+1} \dots c_{i,n}\right] \quad (8)$$

where u and m define the block lengths. Within each block every error pattern with n_e errors is generated. This method guarantees that only the most unreliable bits are considered for the error test pattern generation. With this assumption the number of BCH decoder invocations O_{BCH} is calculated as follows:

$$O_{BCH} = \left[\sum_{l=0}^{n_e} \binom{u}{l}\right] \left[\sum_{l=0}^{n_e} \binom{m}{l}\right]. \quad (9)$$

The result serves as an upper bound as the threshold κ is neglected in this case. Fig. 2 shows the number of BCH decoding invocations for one and two errors per block.

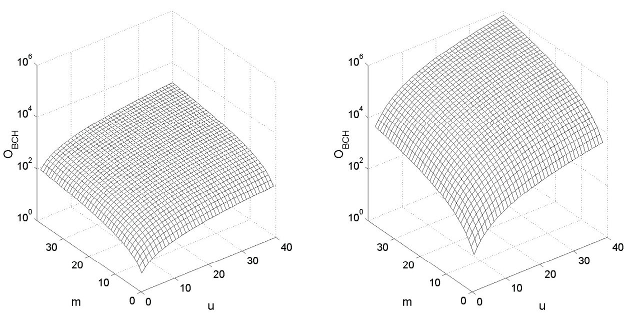

Fig. 2. BCH decoding complexity for error patterns with one (left) and two (right) assumed errors n_e for each block.

The complexity quickly increases as m and u increase. Also a significant difference is visible when comparing one and two errors per block. To achieve a decoding with moderate complexity, low values have to be choose for m and u. Furthermore, there are significant disadvantages regarding the computational complexity with $n_e > 1$ in each block.

V. Simulation Results

As the performance parameter, the packet error rate (PER) is shown in Fig. 3 using FM0 spreading over a Rayleigh fading channel. One packet includes the RN16 and the EPC. The PER is plotted over the Signal-to-Noise-Ratio (SNR) which is the ratio of the symbol energy E_s and the noise power spectral density N_0. The modified Chase algorithm with different parameters is compared to a transmission with a hard-decoded BCH code and an uncoded transmission.

A coding gain of 1 dB is visible between Chase decoding and a common BCH code for a PER$=10^{-1}$. Note that this PER is quite high but it is sufficient if the communication environment is very rough and a detection algorithm is also part of the signal processing. In this case the high PER is counteracted with a possible retransmission during the communication. It should be mentioned that a coding gain with the Chase algorithm compared to hard-input decoding is only provided up to a PER$\approx 2 \cdot 10^{-2}$. This behavior is explainable with the few errors occurring at such a PER level, where the additional performance of the Chase algorithm does not make any difference. Also due to very few errors for high SNRs a coding gain is only achieved between $E_s/N_0 \approx 16 \dots 31\ dB$. Note, that the parameter variations of the Chase decoder lead to an additional coding gain $< 0.1\ dB$. The following table provides an overview over the complexity of the codes used in Fig. 3. Note that these values serve as an upper bound as κ is not taken into consideration.

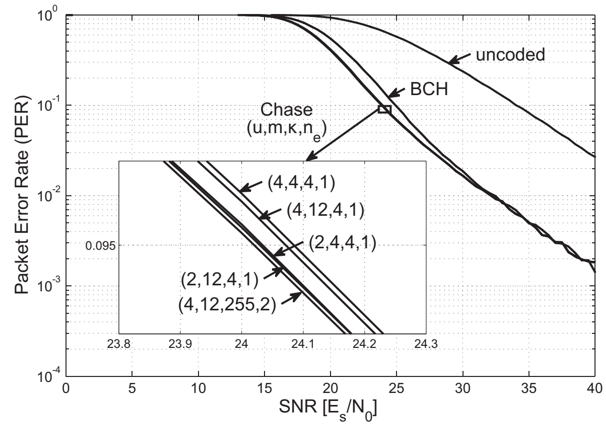

Fig. 3. PER for varying Chase-decoded transmissions with FM0 spreading over a Rayleigh channel. As a reference the uncoded and BCH decoded transmission is also presented.

TABLE I
Number of BCH decoder invocations for the presented codes with Chase decoding

u	m	n_e	O_{BCH}
4	4	1	16
4	12	1	48
2	4	1	8
2	12	1	24
4	12	2	76032

The complexity increases drastically using $n_e > 1$ even if the performance hardy improved as seen in Fig. 3. It is clear that the parameters have to be chosen in a way that the complexity is low in order to achieve a good trade-off between performance and complexity. Also, it is noteworthy that the algorithm performs better when $u = 2$ (compared to $u = 4$). The second block provides more unreliable bits in this case. This results in a more balanced treatment of these bits. The gain is rather small, though.

It also should be mentioned that the results for the Miller schemes are generally comparable to the results shown in this work. Note that the performance of the BCH decoder decreases as the length of the Miller codes increase. The reason is the general increasing of transmission performance in such cases [6]. This effect also has a minor influence on the Chase algorithm. As a result the transmission with the FM0 scheme should serve as an upper bound for the transmission over a Rayleigh channel. Nevertheless when the channel conditions degrade which is a realistic scenario for RFID applications [10] [13], the coding gain increases slightly.

VI. Conclusion

This paper presents an FEC approach with soft-input values for RFID applications. An additional coding gain of $1\ dB$ is achieved between soft- and hard-input bits in this case. A low complexity version of the decoding algorithm can be chosen, as the increase in decoding complexity does not provide significant performance differences. Note, that there are only minor modifications necessary to use this decoding scheme in the EPCglobal protocol, as it has to be implemented on reader side where a complex signal processing unit is already available.

For future work different concepts regarding a computational efficient decoding could be investigated. Also different code classes could be compared to the presented results. Codes with iterative decoding like Low-Density-Parity-Check (LDPC) [14] provides an additional coding gain compared to the codes shown in this work.

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